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AN INSTRUMENT FOR THE SPECTROSCOPIC DETERMINATION OF PRECIPITABLE ATMOSPHERIC WATER VAPOR, AND ITS CALIBRATION

By IRVING F. HAND

[Weather Bureau, Washington, D. C., January 1940]

The regular daily determination of the amount of precipitable water in the atmosphere is of importance in meteorology for both practical and theoretical purposes. Surface determinations have been made by means of the psychrometer ever since the earliest days of meteorology; while the vertical distribution of water vapor has been determined to limited heights by kite, balloon, and airplane flights and, more recently, by means of the radiosonde. Some years ago, the Weather Bureau initiated optical determinations of precipitable water by pyrheliometric measurements of solar radiation through red and yellow filters which cut off long-wave radiation at approximately 0.61 μ and 0.51 μ, respectively.[1] However, this method is subject to considerable uncertainty, especially because the filters do not cut off sharply, and because of various assumptions, for example, the adoption of the value 1.3 μ for the average size of dust particles in the free atmosphere; our own atmospheric dust observations,[2] as well as observations by others, show the impracticability of using a constant factor for all environments.

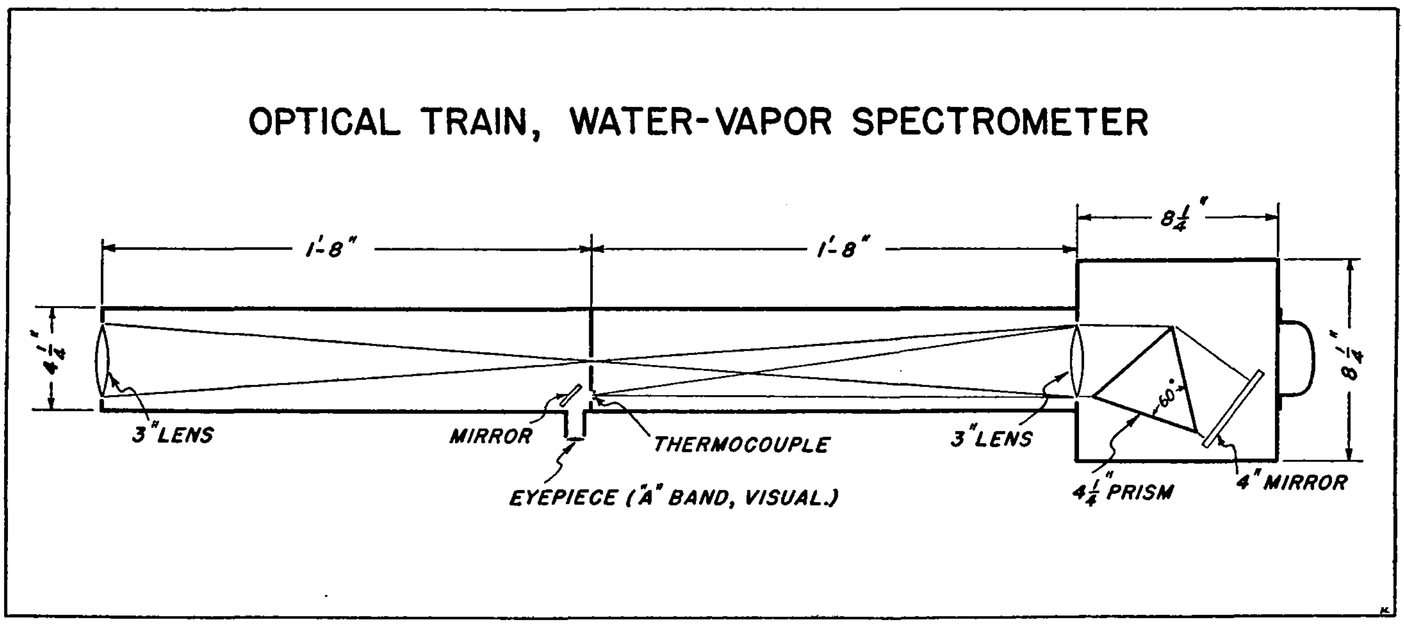

FIGURE 1.—Optical train of the water-vapor spectroscope.

The Weather Bureau is now greatly indebted to the Smithsonian Institution which, through the courtesy of Charles G. Abbot and L. B. Aldrich, designed and fabricated for the Weather Bureau an improved type of water-vapor spectroscope, of design similar to the one used by the Smithsonian Astrophysical Observatory about 8 years ago. We are further indebted to officials of the same Institution in permitting the calibration of the instrument at its two solar constant stations at Burro Mountain, N. Mex., and Table Mountain, Calif. At the first-named station Alfred F. Moore and Alfred D. Froiland more than doubled the usual total number of bolometric runs in order to obtain as many comparisons as possible; they also took turns in keeping the instrument pointed on the sun. Similar cooperation was furnished at Table Mountain by Fred A. Greeley and Stanley Warner.

The water-vapor instrument consists essentially of a spectroscope containing a collimator lens and a 60°-prism in a Littrow mounting, a lens to focus the solar rays on a slit ½ millimeter in width, and a thermocouple having two rectangular surfaces as nearly identical as it is practical to make them. Figure 1 shows the optical train, and figures 3 and 4 an exterior view of the instrument. The thermocouple,

[1] Kimball, Herbert H., and Hand, Irving F. The use of glass color screens in the study of atmospheric depletion of solar radiation. Mo. Wea. Rev., March 1933. 61: 80-83.
[2] Hand, Irving F. The character and magnitude of the dense dust-cloud which passed over Washington, D. C., May 11, 1934. Mo. Wea. Rev., 62: 156-157. May 1924.

designed and made by Leland B. Clark of the Smithsonian Institution, is of a new and highly efficient design. It is so arranged that by moving it into three different fixed positions, measurements may be made in different parts of the spectral band: The two sections of the solar energy spectrum observed are (*A*), a 0.003μ width centered around 0.9560μ, where the energy curve is not appreciably affected by water-vapor absorption; and (*B*), a 0.003μ width in the

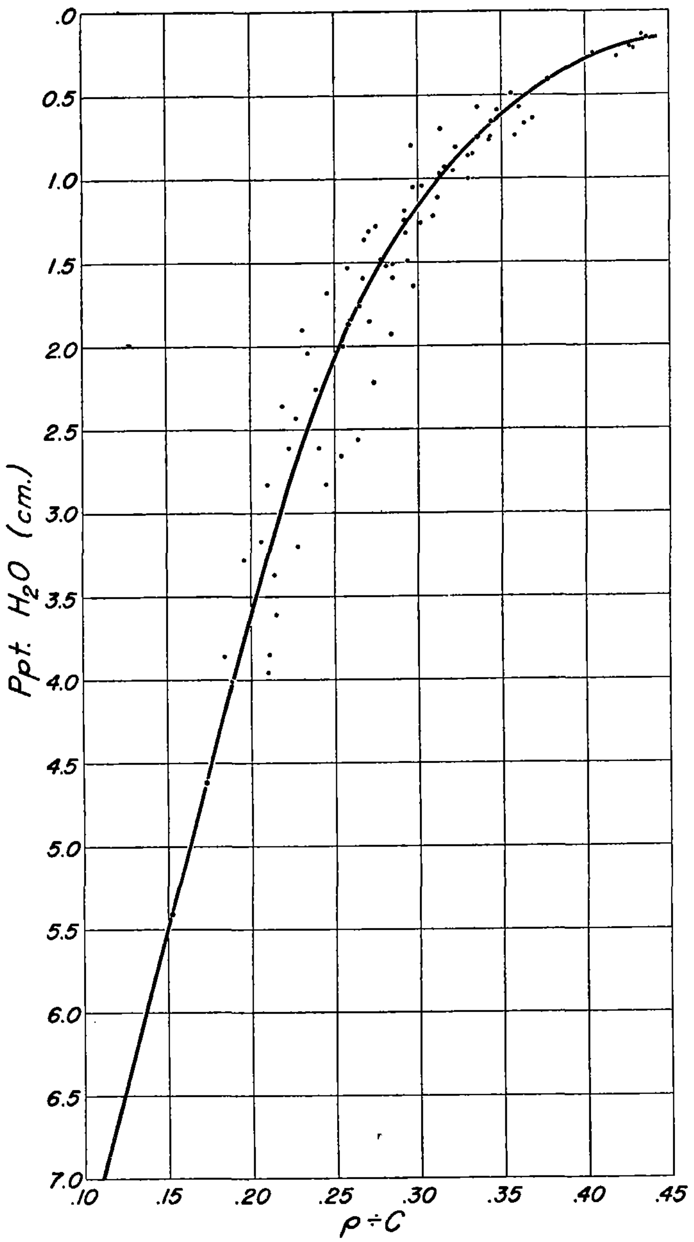

Figure 2.—Amounts of precipitable water corresponding to different ratios obtained by readings with the spectroscope.

center of the rho water-vapor absorption band at wavelength 0.935μ. The base line (*C*) is obtained by completely shading one strip. A high-sensitivity galvanometer is used for all measurements. In position 1, one strip on *A* and the other on *B*, we measure the differential between rho and the crest, or the diminution in energy owing to water-vapor absorption; in position 2, one strip on *B* and the other completely shaded, we obtain the height of rho above the base line; in position 3, one strip on *A* and the other completely shaded, we determine the energy at the crest, which should equal the sum of the energies obtained in the first two positions.[3] This value also may be used for a rough determination of the total normal-incidence radiation.

To eliminate errors arising from inequalities in strip characteristics, the strips are reversed after making the initial reading in each position. Although any two of the positions would suffice for a reading, in actual practice all three positions are read and, as an added check, immediately reread in reverse order to minimize arithmetical errors.

The instrument is kept directed to the sun, manually, by means of a sight at the outer end of the tube through which a pencil of rays passes on to a target at the lower end. A circular opening near the outer end, through which the observer may see when the solar rays are concentrated centrally on the slit, enables him to make an appropriate spot on the target. A small prism projects the portion of the spectral band containing the *A* line at 0.760μ to a field which may be viewed by means of an eye-piece containing a cross hair, in order to obtain an approximate setting of the strips on the rho band. The final setting is effected by reading the instrument in position 2 and adjusting the mirror until a minimum reading is obtained. If the instrument is mounted rigidly in a fixed position neither of these adjustments is necessary except at infrequent intervals as checks. Owing to the great length of the tube and the extreme sensitivity of the thermocouple, it is necessary for one observer to continually make both altitude and aximuth adjustments, and at the same time change the position of the thermopile and turn it through 180° upon signal from the observer during readings.

At the two Smithsonian solar-constant stations, complete records of the solar energy curve from 0.34μ to 2.34μ are made on each clear day by means of the vacuum bolometer [4]; six bolographs are used for the determination of the solar constant on very clear days, and three on less clear days. As previously stated, in order to obtain as many comparisons as possible during these tests, the number of bolographs was increased to as much as three times normal on exceptionally clear days. By reduction of these bolographs the Smithsonian observers have calculated the amount of precipitable water in the atmosphere during each of the runs and these values have been plotted as ordinates against the readings of the new spectroscope as abscissas, fig. 2. Aldrich believes that the Table Mountain results give more accurate values of precipitable water in the atmosphere than the Burro Mountain readings; hence the Table Mountain calibrations have been used exclusively in preparing table 1, which gives the amounts of precipitable water corresponding to different readings of the new instrument.

All values obtained at Table Mountain (with the exception of those obtained on the morning of October 20 when the instrument obviously was out of adjustment) have been utilized for the calibration. The probable error of a single observation, calculated from the line of best fit of all the readings by the formula $0.6745\sqrt{\frac{\Sigma v^2}{n-1}}$, is ± 0.19 cm.

The individual half-day runs were also plotted, and the probable error of a single observation calculated from the lines of best fit; smooth curves were drawn, rather than lines zig-zagging from point to point. In general the curves of the individual half-day runs are very similar to

[3] Moore, A. F. Scouting for a site for a solar radiation station. Smithsonian Misc. Coll. Vol. 89, No. 4. Washington, 1933.

[4] Abbot, C. G., Fowle, F. E., and Aldrich, L. B. The Vacuum Bolometer. Annals of the Astrophysical Observatory of the Smithsonian Institution, Volume 4, Chapter 2, pp. 45-64. Washington, 1922.

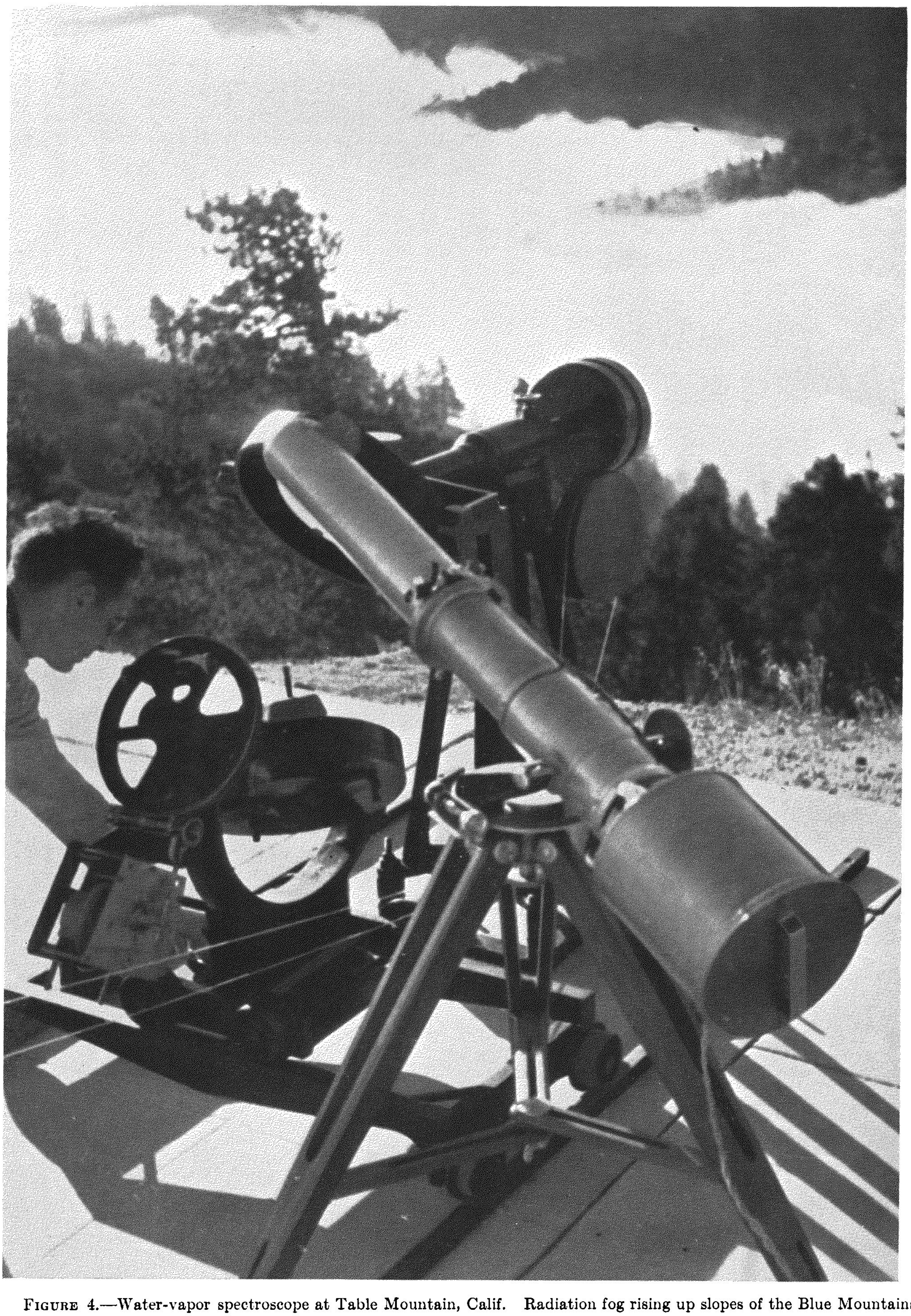

FIGURE 4.—Water-vapor spectroscope at Table Mountain, Calif. Radiation fog rising up slopes of the Blue Mountains.

the curve of all the observations, falling symmetrically on both sides of the latter; the instrument was adjusted on rho immediately preceding each run, but since it was impossible to exactly duplicate the settings with the temporary set-up of the instrument, each run was made with the strips set on a slightly different portion of the rho band, which explains why the individual days vary even though they closely parallel one another. It has been calculated that one half of the probable error of ±0.19 cm. is due directly to these improper adjustments on rho; to eliminate this portion of the error, we shall replace the cross hair so that it bisects the double A line when the best possible setting on rho is made, and the settings may then be effected with great accuracy and with assurance that all are alike. The probable error of future readings should be thus reduced from ±0.19 cm. to about ±0.10 cm. This reduction is highly important because we shall be concerned chiefly with changes in the amounts of atmospheric water.

Table 2 gives the probable errors of single observations from the individual lines of half-day runs.

TABLE 1.—*Amounts of precipitable water in centimeters corresponding to different ratios of ρ/C obtained with the water-vapor spectroscope*

ρ/C	cm.	ρ/C	cm.	ρ/C	cm.	ρ/C	cm.	ρ/C	cm.	ρ/C	cm.	ρ/C	cm.
0.110	7.03	0.160	5.13	0.210	3.28	0.260	1.84	0.310	1.02	0.360	0.54	0.410	0.24
0.111	6.99	0.161	5.09	0.211	3.25	0.261	1.82	0.311	1.01	0.361	.53	0.411	.23
0.112	6.96	0.162	5.05	0.212	3.21	0.262	1.80	0.312	1.00	0.362	.52	0.412	.23
0.113	6.92	0.163	5.01	0.213	3.18	0.263	1.78	0.313	.99	9.363	.52	0.413	.23
0.114	6.88	0.164	4.97	0.214	3.15	0.264	1.76	0.314	.98	0.364	.51	0.414	.22
0.115	6.85	0.165	4.93	0.215	3.11	0.265	1.74	0.315	.97	0.365	.50	0.415	.22
0.116	6.81	0.166	4.89	0.216	3.08	0.266	1.72	0.316	.96	0.366	.50	0.416	.22
0.117	6.77	0.167	4.85	0.217	3.04	0.267	1.70	0.317	.95	0.367	.49	0.417	.21
0.118	6.74	0.168	4.80	0.218	3.00	0.268	1.68	0.318	.94	0.368	.48	0.418	.21
0.119	6.70	0.169	4.76	0.219	2.96	0.269	1.66	0.319	.92	0.369	.48	0.419	.21
0.120	6.67	0.170	4.72	0.220	2.93	0.270	1.64	0.320	.91	0.370	.47	0.420	.20
0.121	6.63	9.171	4.69	0.221	2.90	0.271	1.62	0.321	.90	0.371	.47	0.421	.20
0.122	6.59	0.172	4.65	0.222	2.87	0.272	1.60	0.322	.89	0.372	.46	0.422	.20
0.123	6.55	0.173	4.62	0.223	2.54	0.273	1.58	0.323	.88	0.373	.46	0.423	.19
0.124	6.51	0.174	4.58	0.224	2.81	0.274	1.56	0.324	.87	0.374	.45	0.424	.19
0.125	6.48	0.175	4.54	0.225	2.78	0.275	1.55	0.325	.86	0.375	.44	0.425	.19
0.126	6.44	0.176	4.51	0.226	2.74	0.276	1.53	0.326	.85	0.376	44	0.426	.19
0.127	6.40	0.177	4.47	0.227	2.71	0.277	1.52	0.327	.84	0.377	.43	0.427	.18
0.128	6.37	0.178	4.43	0.228	2.68	0.278	1.50	0.328	.83	0.378	.42	0.428	.18
0.129	6.34	0.179	4.40	0.229	2.65	0.279	1.49	0.329	.82	0.379	.42	0.429	.18
0.130	6.30	0.180	4.36	0.230	2.62	0.280	1.47	0.330	.81	0.380	.41	0.430	.18
0.131	6.26	0.181	4.32	0.231	2.59	0.281	1.45	0.331	.80	0.381	.40	0.431	.18
0.132	6.22	0.182	4.28	0.232	2.56	0.282	1.44	0.332	.79	0.382	.40	0.432	.17
0.133	6.18	0.183	4.25	0.233	2.53	0.283	1.42	0.333	.78	0.383	.39	0.433	.17
0.134	6.14	0.184	4.21	0.234	2.50	0.284	1.40	0.334	.77	0.384	.38	0.434	.17
0.135	6.11	0.185	4.18	0.235	2.47	0.285	1.38	0.335	.76	0.385	.38	0.435	.17
0.136	6.07	0.186	4.14	0.236	2.45	0.286	1.36	0.336	.75	0.386	.37	0.436	.17
0.137	6.04	0.187	4.11	0.237	2.43	0.287	1.34	0.337	.74	0.387	.36	0.437	.16
0.138	6.00	0.188	4.07	0.238	2.41	0.288	1.32	0.338	.73	0.388	.36	0.438	.16
0.139	5.97	0.189	4.04	0.239	2.38	0.289	1.31	0.339	.72	0.389	.35	0.439	.16
0.140	5.93	0.190	4.00	0.240	2.36	0.290	1.29	0.340	.71	0.390	.34	0.440	.16
0.141	5.89	0.191	3.96	0.241	2.33	0.291	1.28	0.341	.70	0.391	.34	0.441	.16
0.142	5.85	0.192	3.93	0.242	2.30	0.292	1.27	0.342	.69	0.392	.33	0.442	.16
0.143	5.81	0.193	3.90	0.243	2 27	0.293	1.26	0.343	.68	0.393	.33	0.443	.16
0.144	5.77	0.194	3.87	0.244	2.25	0.294	1.25	0.344	.67	0.394	.32	0.444	.15
0.145	5.73	0.195	3.85	0.245	2.22	0.295	1.24	0.345	.66	0.395	.32	0.445	.15
0.146	5.69	0.196	3.80	0.246	2.20	0.296	1.22	0.346	.66	0.396	.31	0.446	.15
0.147	5.65	0.197	3.76	0.247	2.17	0.297	1.20	0.347	.65	0.397	.30	0.447	.15
0.148	5.61	0.198	3.73	0.248	2.14	0.298	1.19	0.348	.64	0.398	.30	0.448	.15
0.149	5.57	0.199	3.69	0.249	2.12	0.299	1.17	0.349	.63	0.399	.29	0.449	.15
0.150	5.54	0.200	3.65	0.250	2.09	0.300	1.15	0.350	.63	0.400	.28	0.450	.15
0.151	5.50	0.201	3.62	0.251	2.07	0.301	1.14	0.351	.63	0.401	.28	------	----
0.152	5.26	0.202	3.58	0.252	2.04	0.302	1.12	0.352	.61	0.402	.27	------	----
0.153	5.42	0.203	3.55	0.253	2.02	0.303	1.11	0.353	.60	0.403	.26	------	----
0.154	5.38	0.204	3.51	0.254	2.00	0.304	1.10	0.354	.60	0.404	.25	------	----
0.155	5.34	0.205	3.48	0.255	1.97	0.305	1.08	0.355	.59	0.405	.25	------	----
0.156	5.30	0.206	3.44	0.256	1.94	0.306	1.07	0.356	.58	0.406	.25	------	----
0.157	5.26	0.207	3.40	0.257	1.92	0.307	1.06	0.357	.57	0.407	.25	------	----
0.158	5.22	0.208	3.36	0.258	1.89	0.308	1.04	0.358	.56	0.408	.24	------	----
0.159	5.18	0.209	3.32	0.259	1.87	0.309	1.03	0.359	.55	0.409	.24	------	----

TABLE 2.—*Probable errors of single observations from individual curves*

Date	Probable error ±	Date	Probable error ±
1939	*cm.*	*1939*	*cm.*
Oct. 17, a. m.	0.14	Oct. 20, p. m.	0.11
Oct. 18, a. m.	.10	Oct. 21, a. m.	.07
Oct. 19, a. m.	.10	Oct. 21, p. m.	.07
Oct. 19, p. m.	.05	Oct. 22, p. m.	.07
Oct. 20, a. m.	.04	Mean	[1] .08

[1] Probable error from plot of all observations, as shown in text, is ±0.19 cm.

According to Harrison [5] the average amounts of precipitable water in a vertical atmospheric column over Washington, D. C., are as follows: Spring, 1.69 centimeters; summer, 3.49 centimeters; autumn, 2.23 centimeters; and winter, 1.00 centimeters. As all of our observations will be made through air masses greater than 1.0, the actual amounts of precipitable water measured will in general exceed these values. We found more consistent readings with larger air masses than with the sun near the zenith, which is explained in part by the fact that incipient clouds passing between the sun and instrument create much larger variations during a series when the sun is nearly overhead than when the sun is at a lower altitude, because the incipient cloud with its water content represents a larger percentage of the total water being measured and its slightest movement, unless it is absolutely uniform, alters the readings.

In table 3 are tabulated the original observations together with the times, air masses, reductions, factors, amounts of precipitable water through the observed air masses and the precipitable water reduced to unit air mass.

TABLE 3.—*Reduction of water-vapor observations*

BURRO MOUNTAIN, N. MEX.

SEPTEMBER 23, 1939

Time	Air mass	Readings			Factor	Ppt. H_2O	Ppt. H_2O 1.0 air mass
						Cm.	*Cm*
8:00 a. m.	2.47	209	101	310	0.326	1.35	0.55
8:14 a. m.	2.22	204	106	309	.341	1.19	.54
8:30 a. m.	2.02	204	109	314	.349	1.10	.54
8:49 a. m.	1.81	201	109	310	.352	.99	.55
9:14 a. m.	1.61	200	114	318	.367	. 89	.55
9:33 a. m.	1.51	203	123	325	.376	.90	.60
10:12 a. m.	1.35	199	126	327	.390	.79	.59
11:10 a. m.	1.22	193	128	327	.404	.63	.52

SEPTEMBER 24, 1939

Time	Air mass	Readings			Factor	Ppt. H_2O	Ppt. H_2O 1.0 air mass
6:48 a. m.	6.18	230	50	279	0.177	5.12	0.83
6:58 a. m.	5.14	231	59	290	.203	4.50	.88
7:10 a. m.	4.21	227	65	299	.232	3.81	.90
7:29 a. m.	3.31	226	75	301	.249	2.85	.86
7:52 a. m.	2.52	227	84	315	.275	2.23	.88
9:37 a. m.	1.51	205	101	304	.328	1.51	1.00
9:56 a. m.	1.40	205	102	313	.339	1.49	1.06
11:04 a. m.	1.23	199	107	315	.359	1.25	1.02

SEPTEMBER 25, 1939

Time	Air mass	Readings			Factor	Ppt. H_2O	Ppt. H_2O 1.0 air mass
6:46 a. m.	6.96	276	40	317	0.128	Off table.	
6:58 a. m.	5.39	279	48	329	.149	5.93	1.10
7:07 a. m.	4.51	278	56	332	.165	4.50	1.00
7:18 a. m.	3.96	274	67	342	.198	3.81	.96
7:24 a. m.	3.53	273	65	341	.196	2.85	.81
8:01 a. m.	2.51	262	81	347	.241	2.23	.89
8:17 a. m.	2.20	256	89	347	.260	1.51	.69
8:39 a. m.	1.93	250	93	351	.280	1.49	.77
9:36 a. m.	1.51	235	110	353	.327	1.25	.83

SEPTEMBFR 26, 1939

Time	Air mass	Readings			Factor	Ppt. H_2O	Ppt. H_2O 1.0 air mass
6:40 a. m.	7.87	261	35	297	0.120	Off table.	
6:48 a. m.	6.51	260	41	301	.136	6.55	1.01
7:00 a. m.	5.14	259	50	309	.162	5.40	1.05
7:12 a. m.	4.23	256	55	313	.179	4.72	1.12
7:30 a. m.	3.32	249	63	319	.211	3.67	1.11
8:00 a. m.	2.50	243	75	320	.238	2.87	1.15
8:32 a. m.	2.00	230	84	316	.270	2.27	1.14
9:35 a. m.	1.50	224	100	326	.311	1.66	1.11
10:51 a. m.	1.27	204	110	316	.352	1.39	1.09

[5] Harrison, Louis P. On the water-vapor in the atmosphere over the United States east of the Rocky Mountains. Mo. Wea. Rev. 59: 470. December, 1931.

TABLE 3.—*Reduction of water-vapor observations*—Continued

SEPTEMBER 27, 1939

Time	Air mass	Readings			Factor	Ppt. H_2O	Ppt. H_2O 1.0 air mass
						Cm.	*Cm.*
6:34 a. m.	9.30	259	36	294	0.121	Off table.	
6:47 a. m.	6.76	266	44	312	.145	6.18	0.91
6:56 a. m.	5.59	259	50	311	.165	5.35	.96
7:04 a. m.	4.77	258	57	316	.182	4.71	.98
7:15 a. m.	4.02	256	66	323	.206	3.81	.95
8:00 a. m.	2.52	238	87	329	.272	2.13	.85
8:35 a. m.	2.00	222	112	343	.344	1.27	.64
9:39 a. m.	1.50	217	114	337	.350	1.05	.70
11:18 a. m.	1.23	202	130	339	.398	.79	.64
1:39 p. m.	1.33	227	145	372	.390	.76	.57
3:45 p. m.	2.14	232	109	349	.313	1.21	.57
4:07 p. m.	2.51	237	99	344	.303	1.52	.61
4:27 p. m.	2.96	238	97	344	.299	1.66	.56
4:43 p. m.	3.52	245	90	345	.279	1.89	.54
4:57 p. m.	4.25	243	84	341	.269	2.27	.53
5:08 p. m.	5.14	239	75	321	.247	2.49	.48
5:18 p. m.	6.30	244	64	314	.215	3.36	.53
5:28 p. m.	7.98	246	57	309	.196	4.24	.53

SEPTEMBER 28, 1939

Time	Air mass	Readings			Factor	Ppt. H_2O	Ppt. H_2O 1.0 air mass
6:39 a. m.	8.46	234	85	323	0.271	2.23	.26
6:49 a. m.	6.72	233	92	325	.283	1.89	.28
7:03 a. m.	5.05	233	104	333	.304	1.34	.27
7:14 a. m.	4.18	226	109	337	.327	1.05	.25
7:35 a. m.	3.28	217	118	339	.356	.85	.26
8:04 a. m.	2.51	212	123	340	.372	.69	.27
8:36 a. m.	2.01	205	128	340	.391	.59	.29
9:41 a. m.	1.50	200	136	332	.401	.48	.32
11:25 a. m.	1.23	190	137	335	.426	.42	.34
1:33 p. m.	1.32	195	128	331	.404	.56	.42
3:17 p. m.	1.84	208	123	337	.377	.55	.30
3:32 p. m.	2.00	214	106	331	.343	.98	.49
3:46 p. m.	2.16	213	109	329	.346	.84	.39
4:07 p. m.	2.50	220	103	327	.323	1.19	.48
4:36 p. m.	3.26	231	89	324	.283	1.70	.52
4:55 p. m.	4.15	236	79	318	.254	2.53	.61
5:08 p. m.	5.02	240	69	309	.223	3.26	.65
5:18 p. m.	6.24	236	66	306	.224	3.51	.56
5:28 p. m.	8.12	231	56	302	[1].216	4.45	.34

[1] Clouds during observation.

SEPTEMBER 29, 1939

Time	Air mass	Readings			Factor	Ppt. H_2O	Ppt. H_2O 1.0 air mass
6:37 a. m.	8.87	234	78	322	0.262	2.52	0.28
6:47 a. m.	6.96	234	83	326	.272	2.02	.29
7:02 a. m.	5.12	234	95	333	.293	1.59	.31
7:14 a. m.	4.21	222	94	321	.303	1.40	.33
7:32 a. m.	3.30	220	95	323	.310	1.20	.36
8:03 a. m.	2.51	213	103	325	.335	.97	.39
8:36 a. m.	2.01	203	113	328	.370	.73	.36
9:41 a. m.	1.50	192	125	323	.400	.58	.39
Mean							.648

TABLE MOUNTAIN, CALIF.

OCTOBER 17, 1939

Time	Air mass	Readings			Factor	Ppt. H_2O	Ppt. H_2O 1.0 air mass
6:56 a. m.	4.90	205	81	300	0.294	1.49	0.30
7:12 a. m.	3.88	186	77	275	.309	1.22	.31
7:37 a. m.	2.99	184	89	276	.330	.86	.29
8:03 a. m.	2.50	179	100	279	.358	.74	.30
8:41 a. m.	2.01	175	98	277	.364	.67	.33
10:05 a. m.	1.50	173	90	267	.347	.59	.39
11:42 a. m.	1.40	182	79	256	.296	.80	.57

OCTOBER 18, 1939

Time	Air mass	Readings			Factor	Ppt. H_2O	Ppt. H_2O 1.0 air mass
1:43 p. m.	1.67	196	81	277	0.292	1.19	0.66
2:05 p. m.	1.80	192	71	267	.275	1.28	.76
2:38 p. m.	1.99	211	79	283	.268	1.36	.68
2:49 p. m.	2.20	210	75	279	.258	1.53	.70
3:08 p. m.	2.49	208	68	276	.246	1.68	.67
3:32 p. m.	3.00	215	64	279	.231	1.90	.63
3:58 p. m.	4.00	214	60	274	.219	2.36	.59
4:14 p. m.	4.99	211	56	267	.210	2.83	.57
4:24 p. m.	5.93	212	53	269	.206	3.17	.53
4:34 p. m.	7.36	213	48	261	.184	3.86	.52

TABLE 3.—*Reduction of water-vapor observations*—Continued

OCTOBER 19, 1939

Time	Air mass	Readings			Factor	Ppt. H_2O	Ppt. H_2O 1.0 air mass
						Cm.	*Cm.*
6:36 a. m.	7.41	245	75	320	0.234	2.04	0.28
6:56 a. m.	4.97	238	96	338	.292	1.33	.27
7:12 a. m.	4.00	237	98	339	.297	1.05	.26
7:39 a. m.	3.00	217	99	322	.321	.83	.28
8:02 a. m.	2.50	224	101	328	.314	.70	.28
8:40 a. m.	2.01	224	109	327	.336	.57	.28
10:07 a. m.	1.50	202	112	318	.361	.57	.38
11:35 a. m.	1.39	212	110	324	.344	.66	.47
12:57 p. m.	1.50	186	94	286	.343	.77	.51
2:26 p. m.	2.00	193	88	283	.316	.93	.46
3:04 p. m.	2.49	192	83	275	.302	1.04	.42
3:33 p. m.	3.09	193	74	279	.293	1.32	.43
3:56 p. m.	4.02	197	68	271	.265	1.76	.44

OCTOBER 20, 1939

Time	Air mass	Readings			Factor	Ppt. H_2O	Ppt. H_2O 1.0 air mass
1:27 p. m.	1.61	207	108	315	0.343	0.75	0.47
2:27 p. m.	2.02	209	99	308	.321	.95	.47
3:04 p. m.	2.41	210	89	303	.302	1.26	.52
3:27 p. m.	3.00	213	83	300	.285	1.59	.53
3:54 p. m.	4.03	214	75	300	.274	2.22	.55
4:09 p. m.	5.01	212	67	289	.254	2.66	.53
4:19 p. m.	5.99	211	64	272	.228	3.20	.53
4:29 p. m.	7.44	215	59	270	.210	3.96	.53

OCTOBER 21, 1939

Time	Air mass	Readings			Factor	Ppt. H_2O	Ppt. H_2O 1.0 air mass
6:32 a. m.	9.35	213	55	272	.211	3.85	0.41
6:42 a. m.	7.21	213	67	284	.245	2.83	.39
6:58 a. m.	4.98	207	78	293	.284	1.93	.39
7:14 a. m.	3.98	206	84	296	.297	1.64	.41
7:42 a. m.	3.02	218	99	317	.312	1.11	.37
8:05 a. m.	2.50	202	99	305	.333	.85	.34
8:45 a. m.	2.01	193	111	308	.369	.64	.32
11:34 a. m.	1.41	184	109	298	.377	.42	.30
1:08 p. m.	1.55	188	100	296	0.356	0.49	0.32
2:22 p. m.	2.00	190	93	289	.336	.75	.38
3:25 p. m.	2.98	202	82	287	.292	1.24	.42
3:35 p. m.	3.29	206	76	283	.271	1.31	.40
3:51 p. m.	3.99	206	71	285	.267	1.59	.40
4:07 p. m.	4.95	207	69	280	.255	2.00	.40
4:17 p. m.	5.90	211	60	275	.227	2.43	.41
4:27 p. m.	7.10	219	50	276	.196	3.28	.46

OCTOBER 22, 1939

Time	Air mass	Readings			Factor	Ppt. H_2O	Ppt. H_2O 1.0 air mass
6:34 a. m.	8.90	215	57	276	.215	3.61	0.41
6:44 a. m.	6.80	214	67	283	.241	2.61	.38
7:00 a. m.	5.02	209	75	289	.271	1.85	.37
7:16 a. m.	4.05	208	80	294	.285	1.51	.37
7:44 a. m.	3:02	197	93	298	.330	1.00	.33
8:07 a. m.	2.49	204	90	300	.313	.97	.39

OCTOBER 23, 1939

Time	Air mass	Readings			Factor	Ppt. H_2O	Ppt. H_2O 1.0 air mass
1:28 p. m.	1.66	208	76	292	0.278	1.48	0.89
1:42 p. m.	1.72	208	77	294	.281	1.52	.88
2:29 p. m.	2.10	206	66	284	.259	1.87	.89
2:59 p. m.	2.50	216	63	289	.239	2.26	.90
3:21 p. m.	2.99	223	61	290	.223	2.61	.87
3:50 p. m.	3.97	221	58	283	.214	3.37	.85
4:05 p. m.	4.98	224	50	278	.188	4.01	.81
4:16 p. m.	5.93	224	47	271	.173	4.61	.78
4:26 p. m.	7.30	222	39	263	.153	5.40	.74
4:37 p. m.	9.71	185	23	208	.111	7.00	.72

OCTOBER 25, 1939

Time	Air mass	Readings			Factor	Ppt. H_2O	Ppt. H_2O 1.0 air mass
7:47 a. m.	3.06	184	127	322	0.419	0.27	0.09
8:13 a. m.	2.51	131	178	315	.429	.22	.09
8:34 a. m.	2.21	175	134	313	.437	.16	.07
8:52 a. m.	2.01	176	131	315	.434	.14	.07
9:19 a. m.	1.80	177	130	311	.247	.21	.12
9:31 a. m.	1.73	181	120	307	.405	.25	.14
Mean							.466

*The factors are obtained from the following formula: ½(AC+AB−AC)/½(AB½BC+AC) where A=Crest; B the rho band and C the base line.